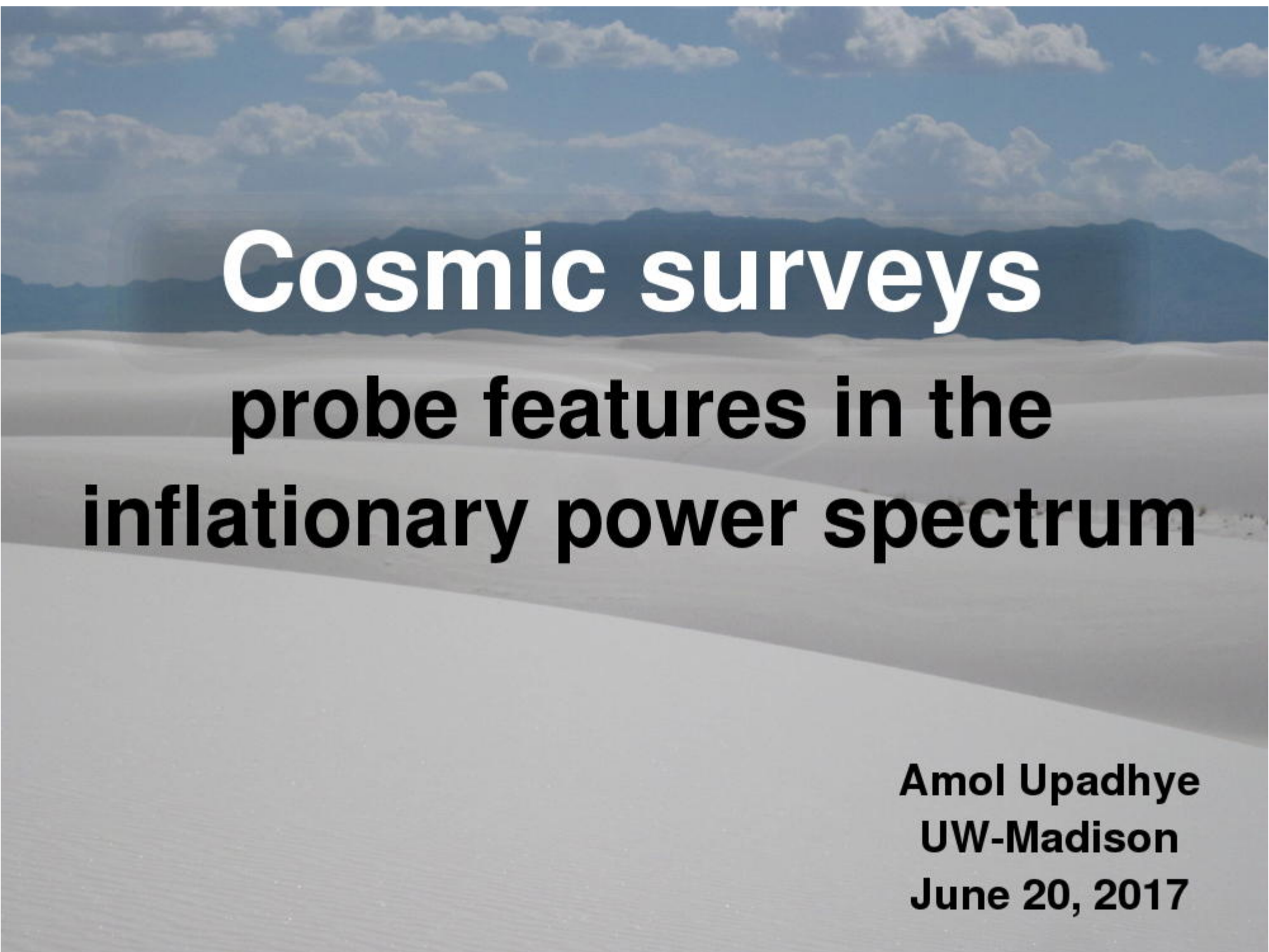


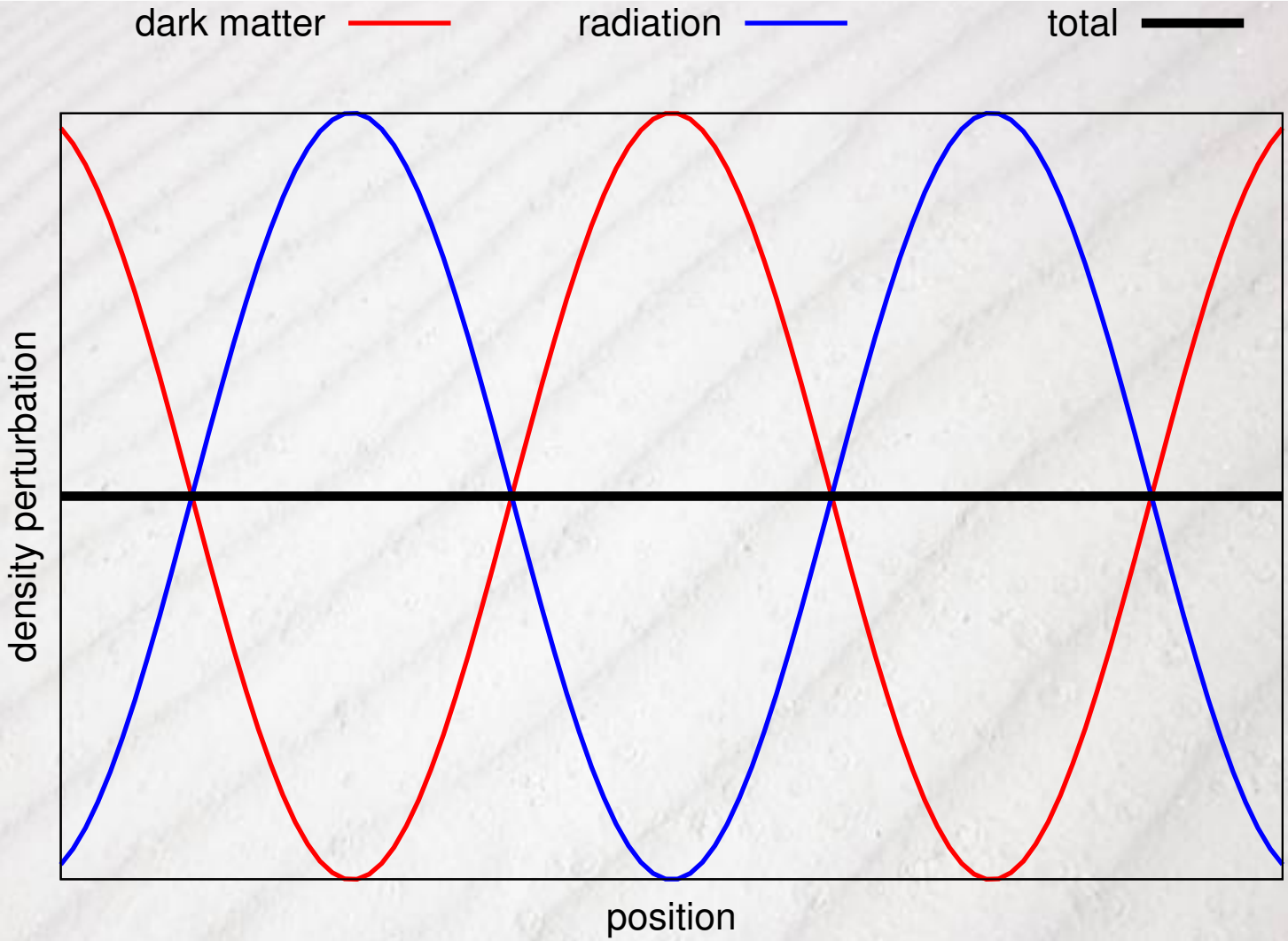
Cosmic surveys
probe features in the inflationary power spectrum

Amol Upadhye
UW-Madison
June 20, 2017

Outline

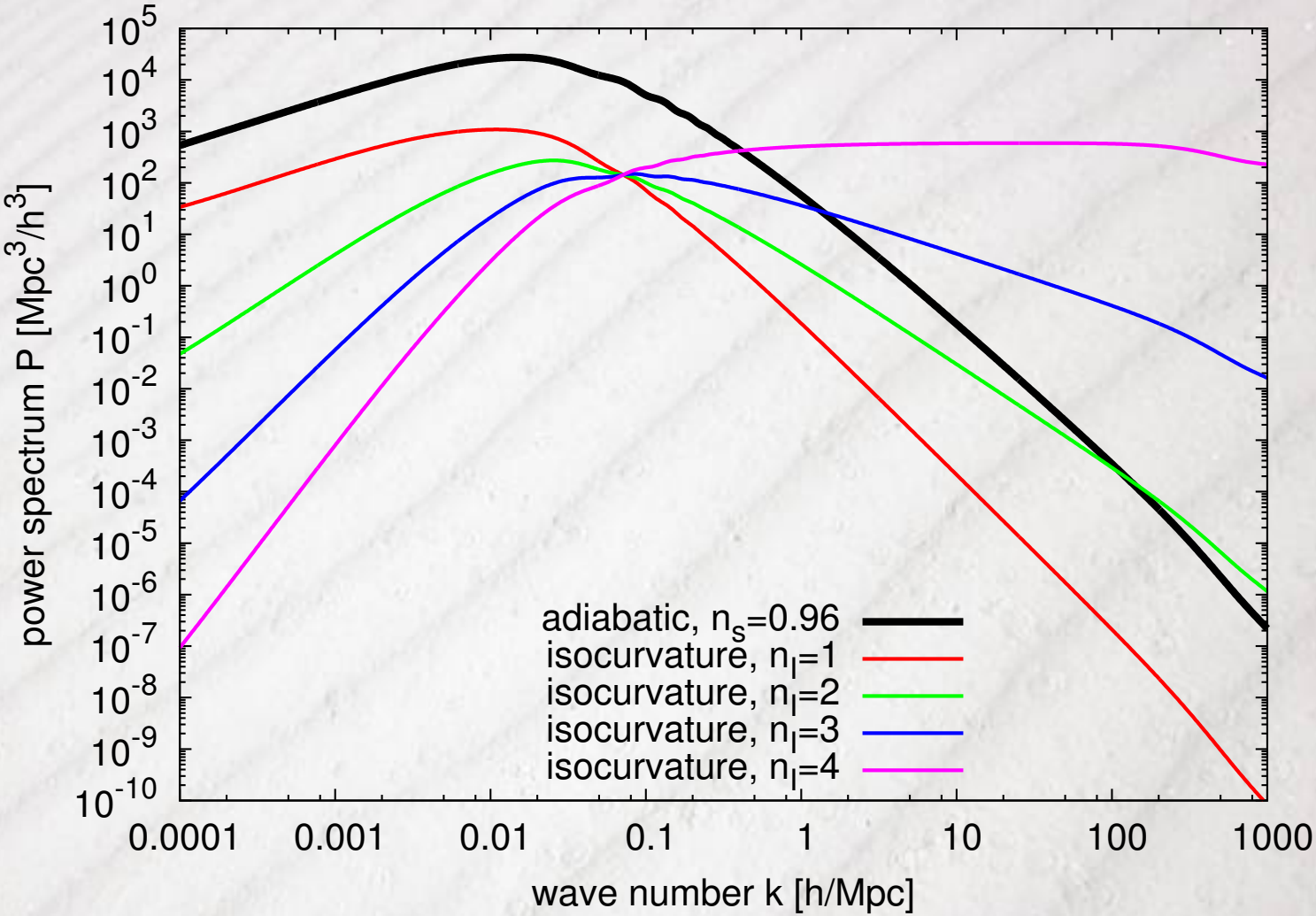
- Motivation: Inflation as a high-energy backlight illuminating new physics (fields and particles)
- Blue isocurvature: What and how
- A simple SUSY axionic model for blue isocurvature
  - Homogeneous field evolution
  - Perturbations and power spectra
- Large-scale cosmic structure is complementary to CMB

Isocurvature



We expect isocurvature perturbations when additional fields are non-negligible during inflation.

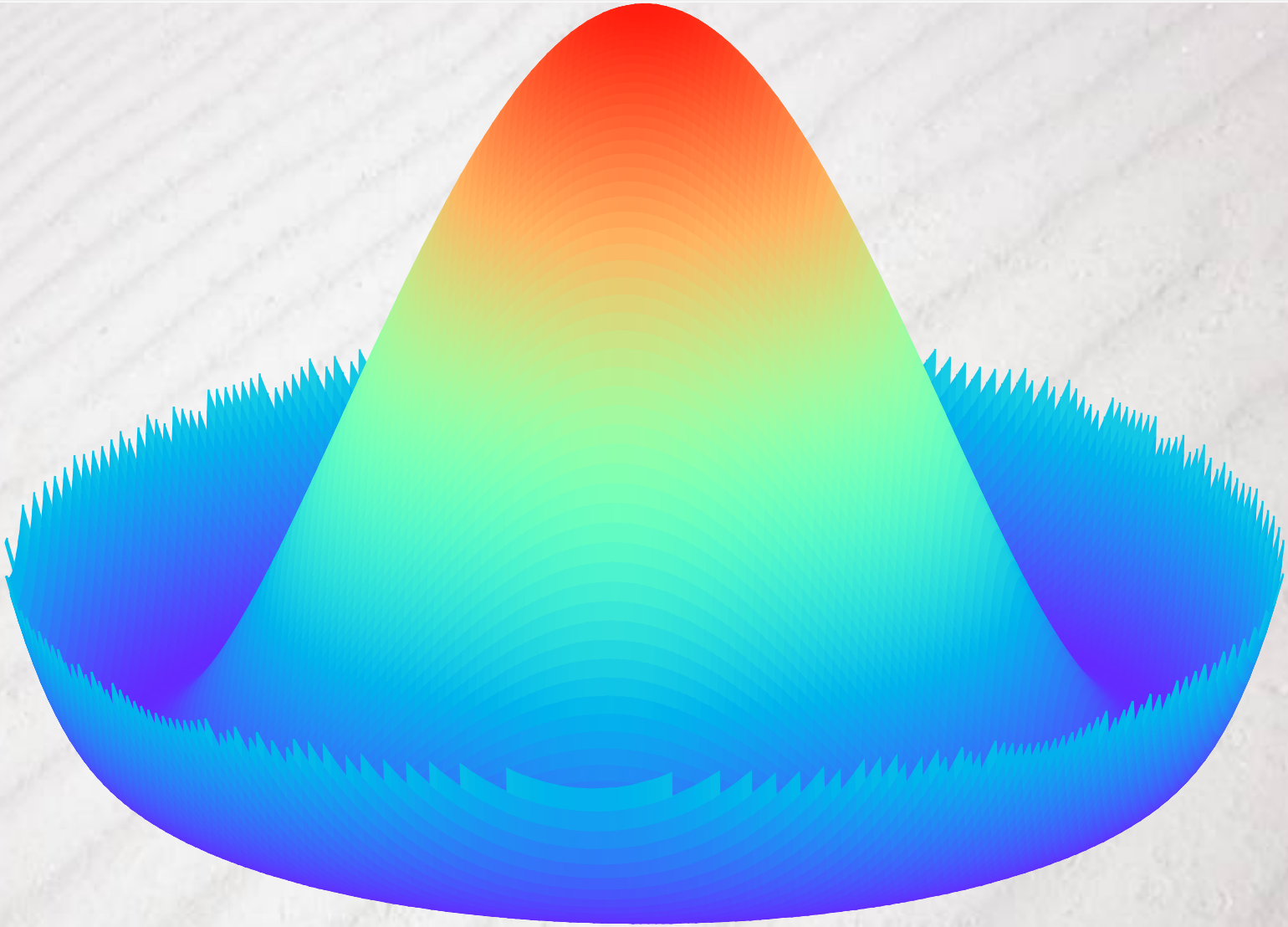
Isocurvature can't be blue at all scales



Isocurvature with a constant spectral index can't be bluer than $n_I = 2.4$.

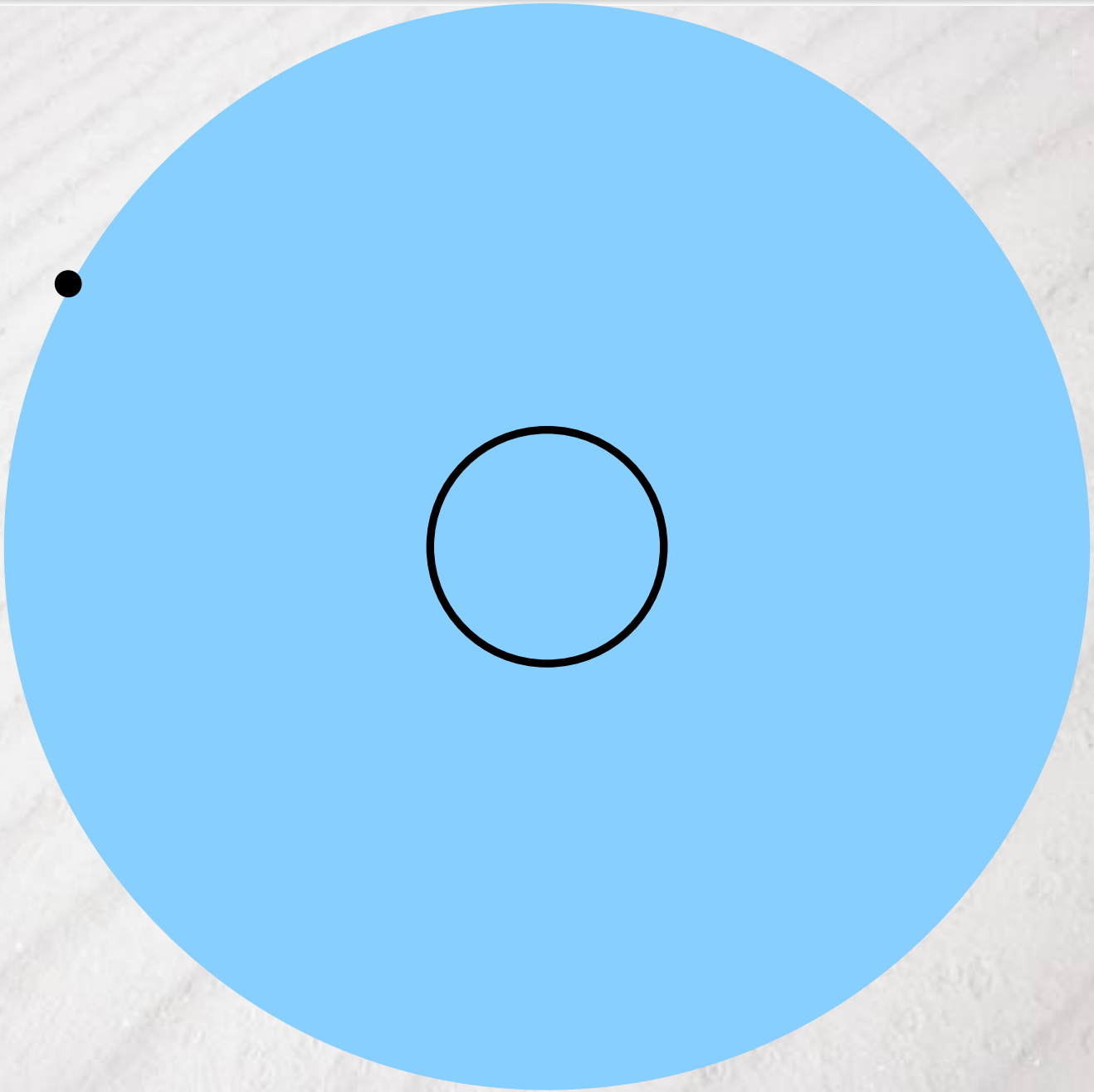
Chung, PRD **94***:043524(2016)[1509.05850]*

Blue spectrum from axionic field



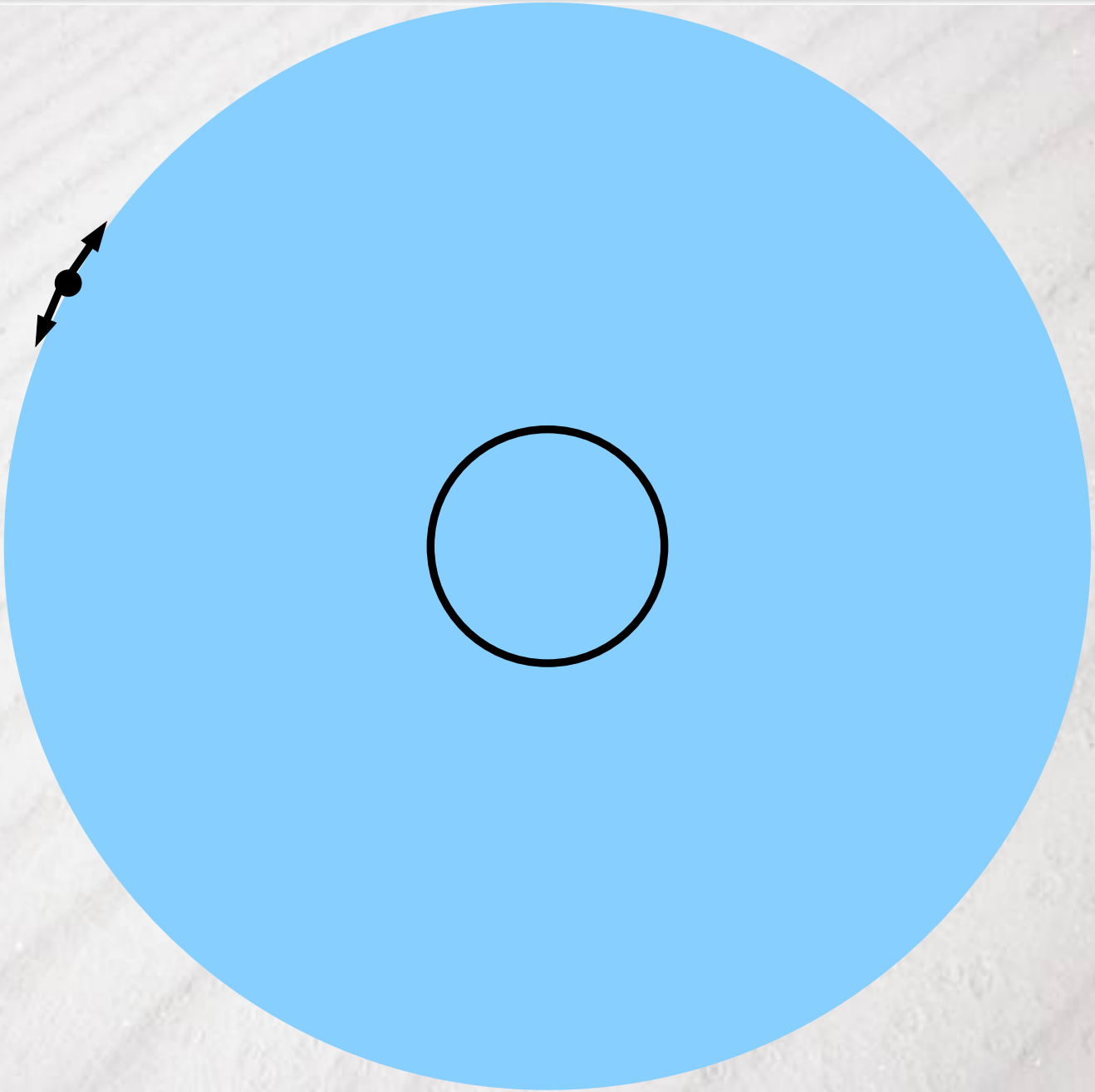
"Hat" potential $V(\Phi) = (\Phi^2 - F_a^2)^2$

Blue spectrum from axionic field



$$\left(\text{out-of-equilibrium axion mass term } \frac{\Box f_{\rm PQ}}{f_{\rm PQ}} a^2 \sim H^2 a^2\right)$$

Blue spectrum from axionic field



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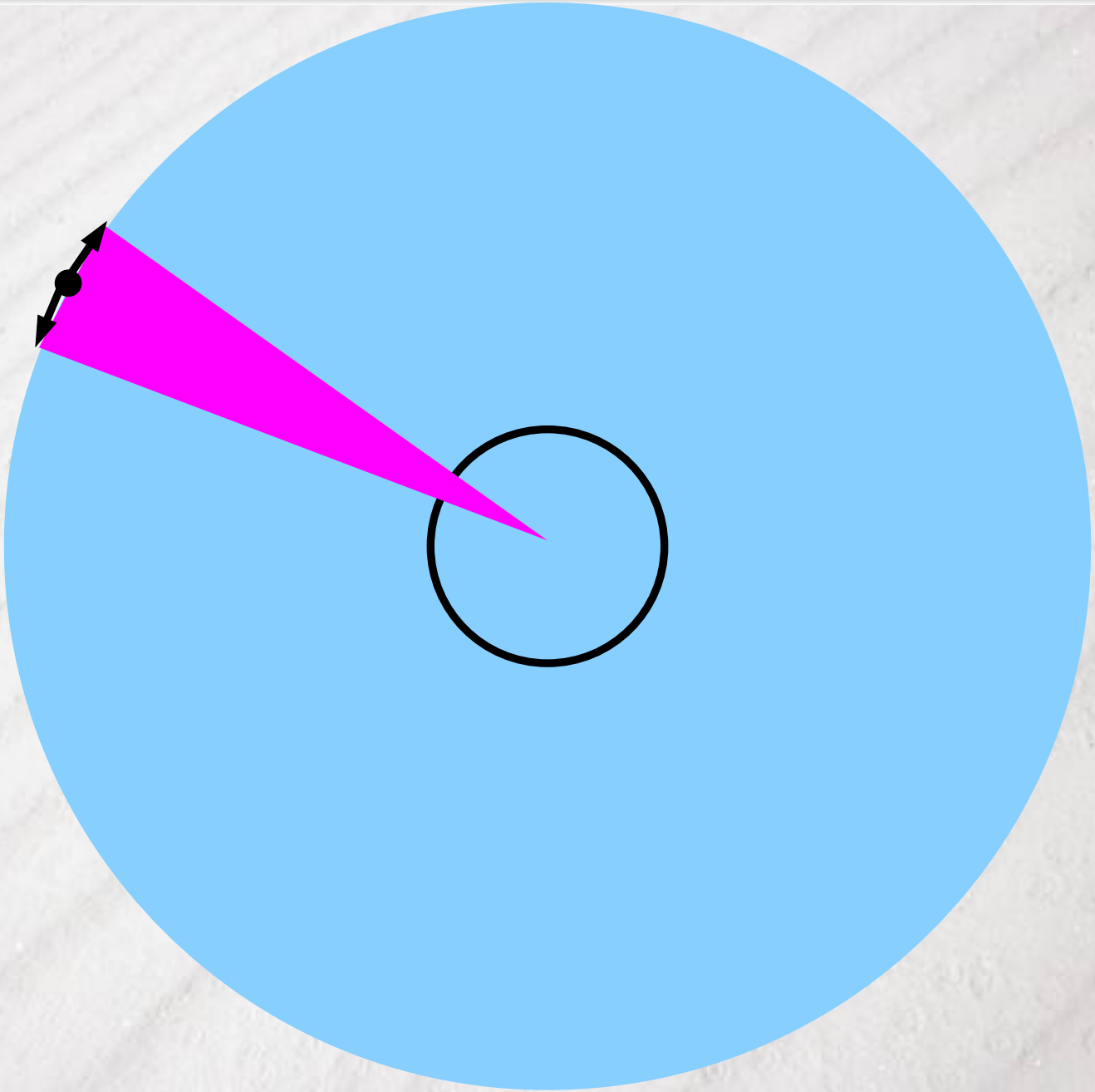

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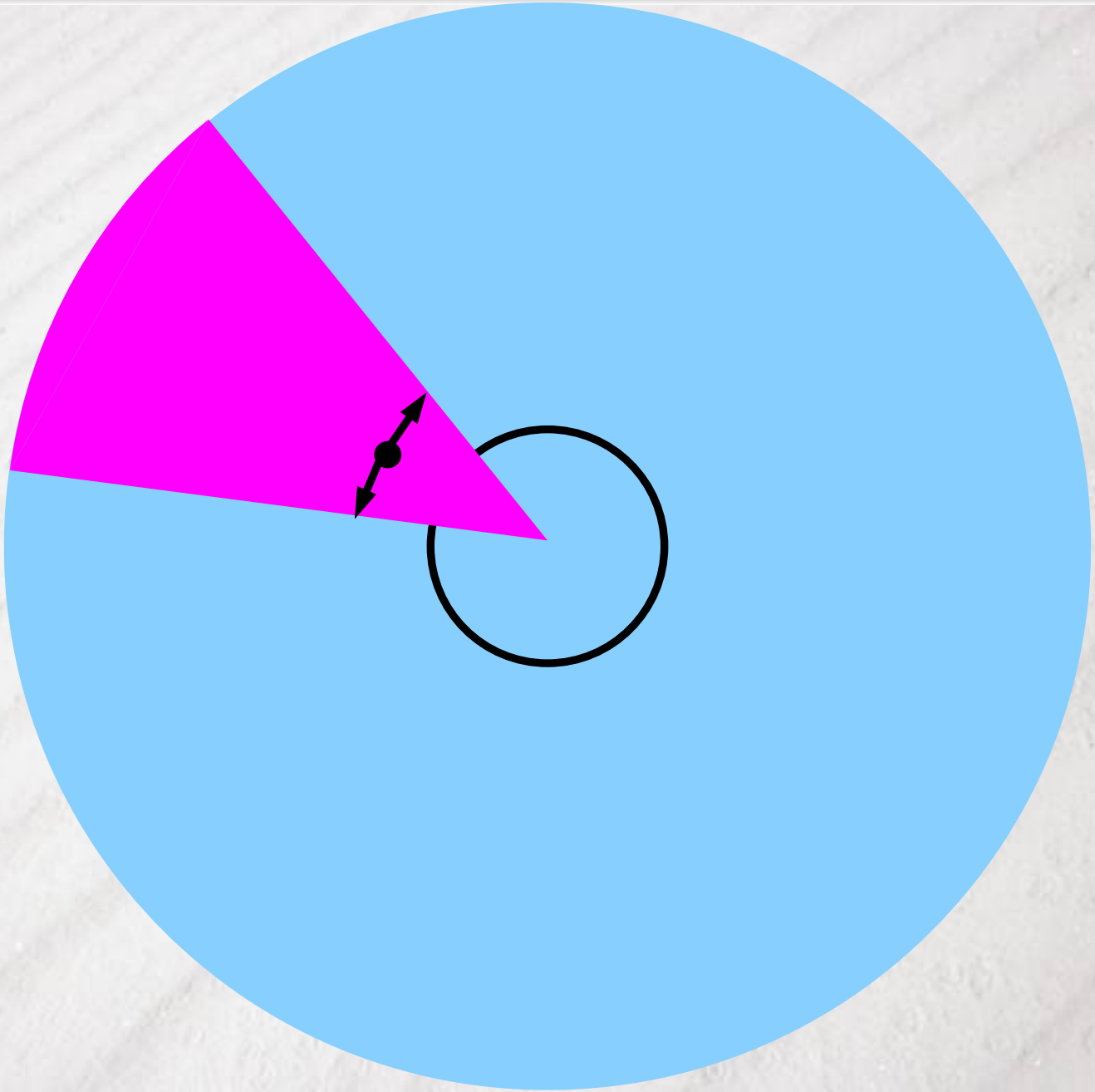
Blue spectrum from axionic field



$$\left(\text{out-of-equilibrium axion mass term } \frac{\Box f_{\rm PQ}}{f_{\rm PQ}} a^2 \sim H^2 a^2\right)$$

Supersymmetric axion model

Superpotential $W = h(\Phi_+\Phi_- - F_a^2)\Phi_0$ for chiral superfields with charges $+1$, -1, and 0 under $U(1)$ Peccei-Quinn symmetry

$$\Rightarrow V = h^2\left|\Phi_+\Phi_- - F_a^2\right|^2 + h^2\left|\Phi_0\right|^2\left(\left|\Phi_+\right|^2 + \left|\Phi_-\right|^2\right)$$

Flat direction: $\Phi_0 = 0$, $\Phi_+\Phi_- = F^2$.

Potential along the flat direction, including Hubble-scale mass corrections (from Kähler potential):

$$V = h^2\left|\Phi_+\Phi_- - F_a^2\right|^2 + c_+H^2\left|\Phi_+\right|^2 + c_-H^2\left|\Phi_-\right|^2$$

- "roll speed" $\gamma = \frac{3}{2}\left(1 - \sqrt{1 - \frac{4}{9}c_+}\right)$ with $\Phi_+ \propto \exp(-\gamma Ht)$;
- spectral index $n_I = 1 + 2\gamma = 4 - 3\sqrt{1 - \frac{4}{9}c_+}$
- blue e-folds: $\eta_* = \gamma^{-1}\log\left(\frac{\Phi_{+,\mathrm{in}}}{F_a}\frac{c_+^{1/4}}{c_-^{1/4}}\right)$

Kasuya and Kawasaki, PRD **80***:023516(2009)[0904.3800]*,

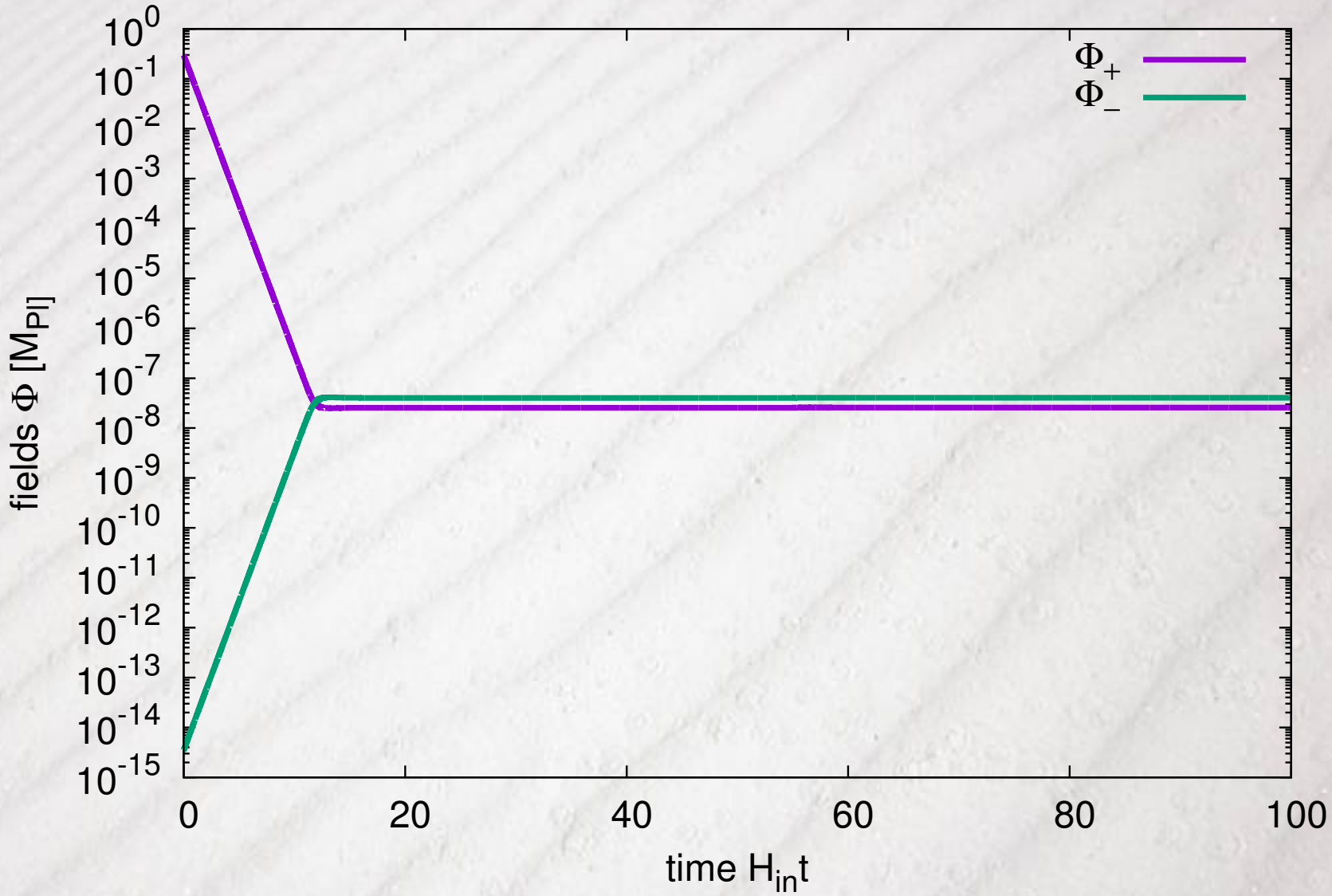
Chung and Yoo, PRD **91***:083530(2015)[1501.05618]*

Power spectrum from analytic arguments

Kasuya and Kawasaki, PRD **80***:023516(2009)[0904.3800]*,

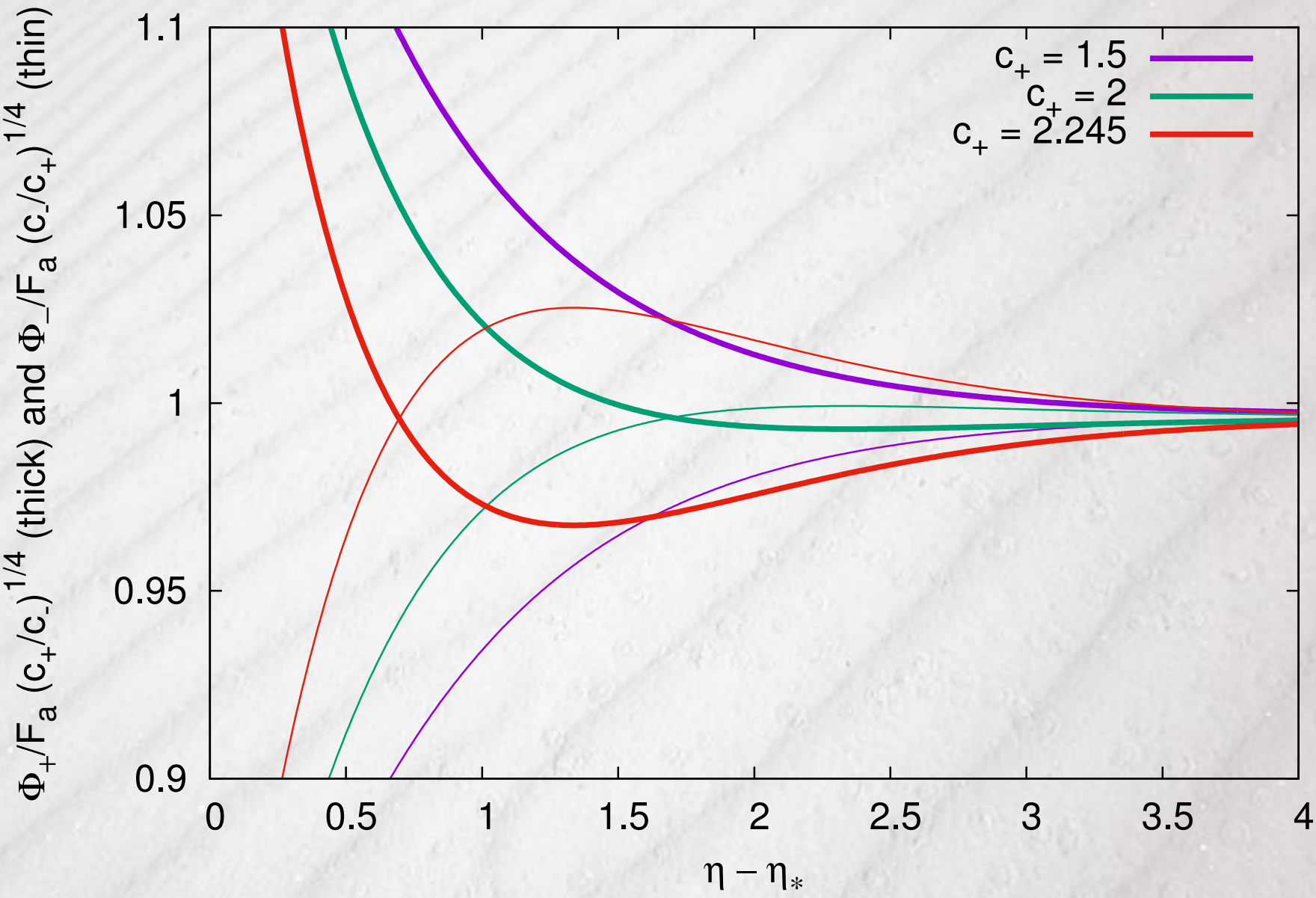
Chung and Yoo, PRD **91***:083530(2015)[1501.05618]*

Field evolution in homogeneous universe

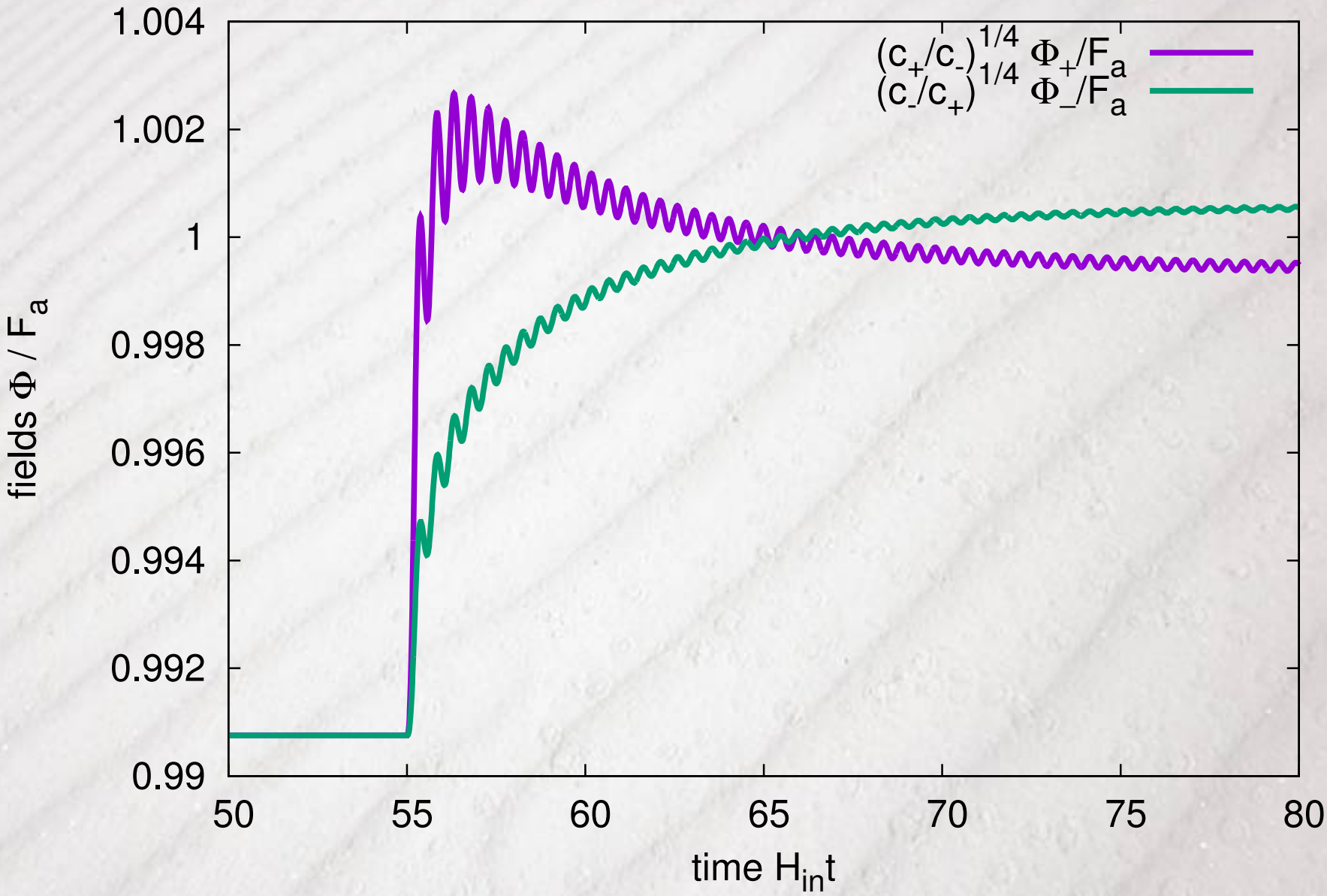


Chung and Upadhye, PRD **95***:023503(2017)[1610.04284]*

Blue-to-flat transition



End of inflation



Evolution of linear perturbations

Perturbations $R_\pm = \mathrm{Re}(\delta\Phi_\pm)$ and $I_\pm = \mathrm{Im}(\delta\Phi_\pm)$ are evolved using

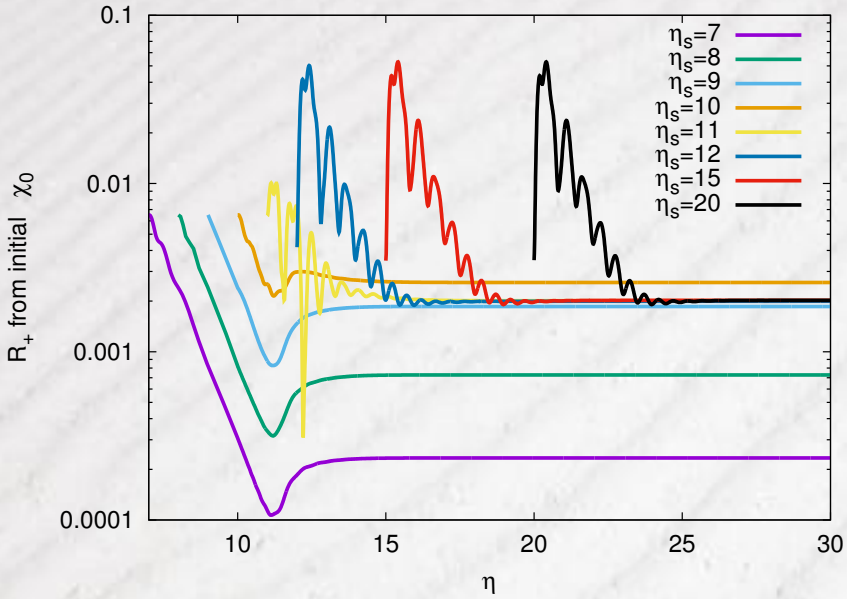
$$\ddot{R}_+ + 3H\dot{R}_+ + \left(c_+H^2 + \frac{k^2}{a^2} + h^2\Phi_-^2\right) R_+ =$$
$$-h^2(\Phi_+\Phi_- - F_a^2)R_- - h^2[\cos(2\theta_+)R_- - \sin(2\theta_+)I_-]\Phi_+\Phi_-$$

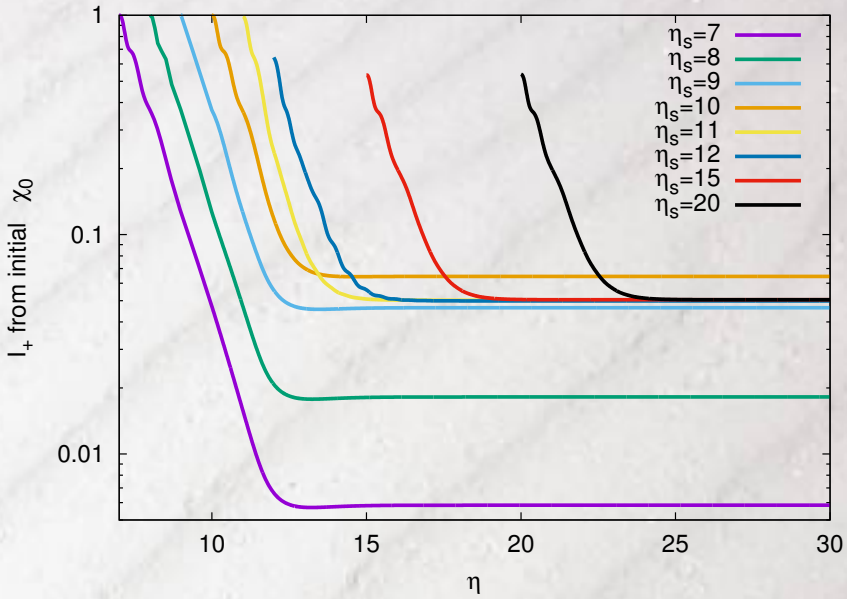
$$\ddot{I}_+ + 3H\dot{I}_+ + \left(c_+H^2 + \frac{k^2}{a^2} + h^2\Phi_-^2\right) I_+ =$$
$$h^2(\Phi_+\Phi_- - F_a^2)I_- - h^2[\cos(2\theta_+)I_- + \sin(2\theta_+)R_-]\Phi_+\Phi_-$$

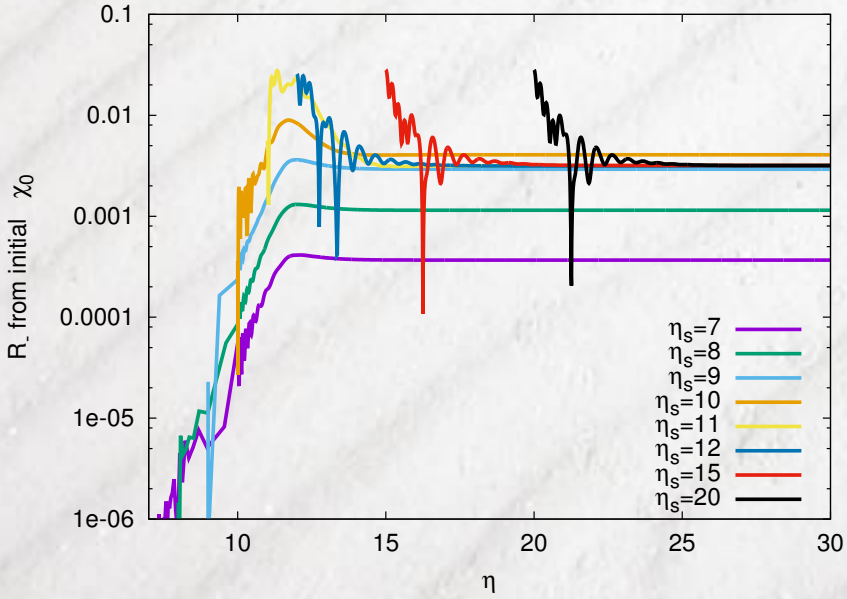
$$\ddot{R}_- + 3H\dot{R}_- + \left(c_-H^2 + \frac{k^2}{a^2} + h^2\Phi_+^2\right) R_- =$$
$$-h^2(\Phi_+\Phi_- - F_a^2)R_+ - h^2[\cos(2\theta_+)R_+ + \sin(2\theta_+)I_+]\Phi_+\Phi_-$$

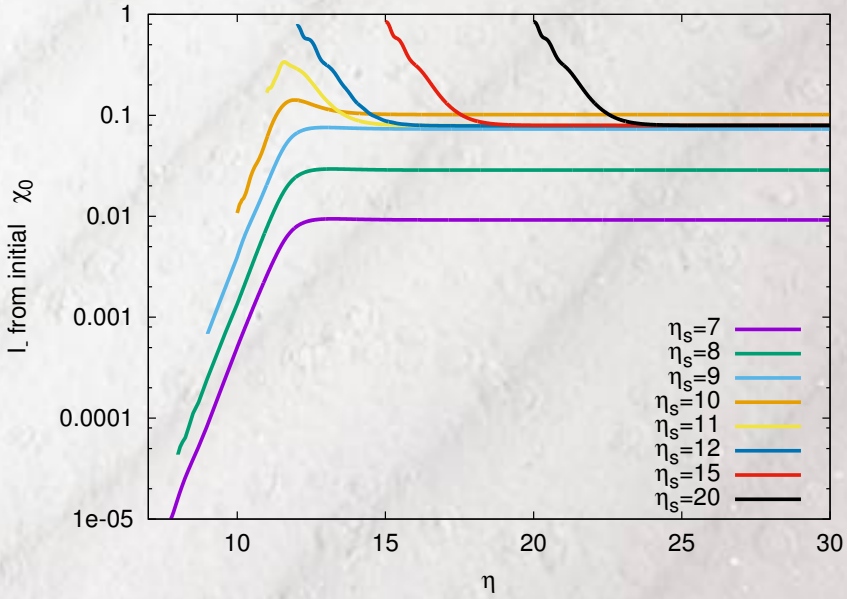
$$\ddot{I}_- + 3H\dot{I}_- + \left(c_-H^2 + \frac{k^2}{a^2} + h^2\Phi_+^2\right) I_- =$$
$$h^2(\Phi_+\Phi_- - F_a^2)I_+ - h^2[\cos(2\theta_+)I_+ - \sin(2\theta_+)R_+]\Phi_+\Phi_-$$

Evolution of linear perturbations



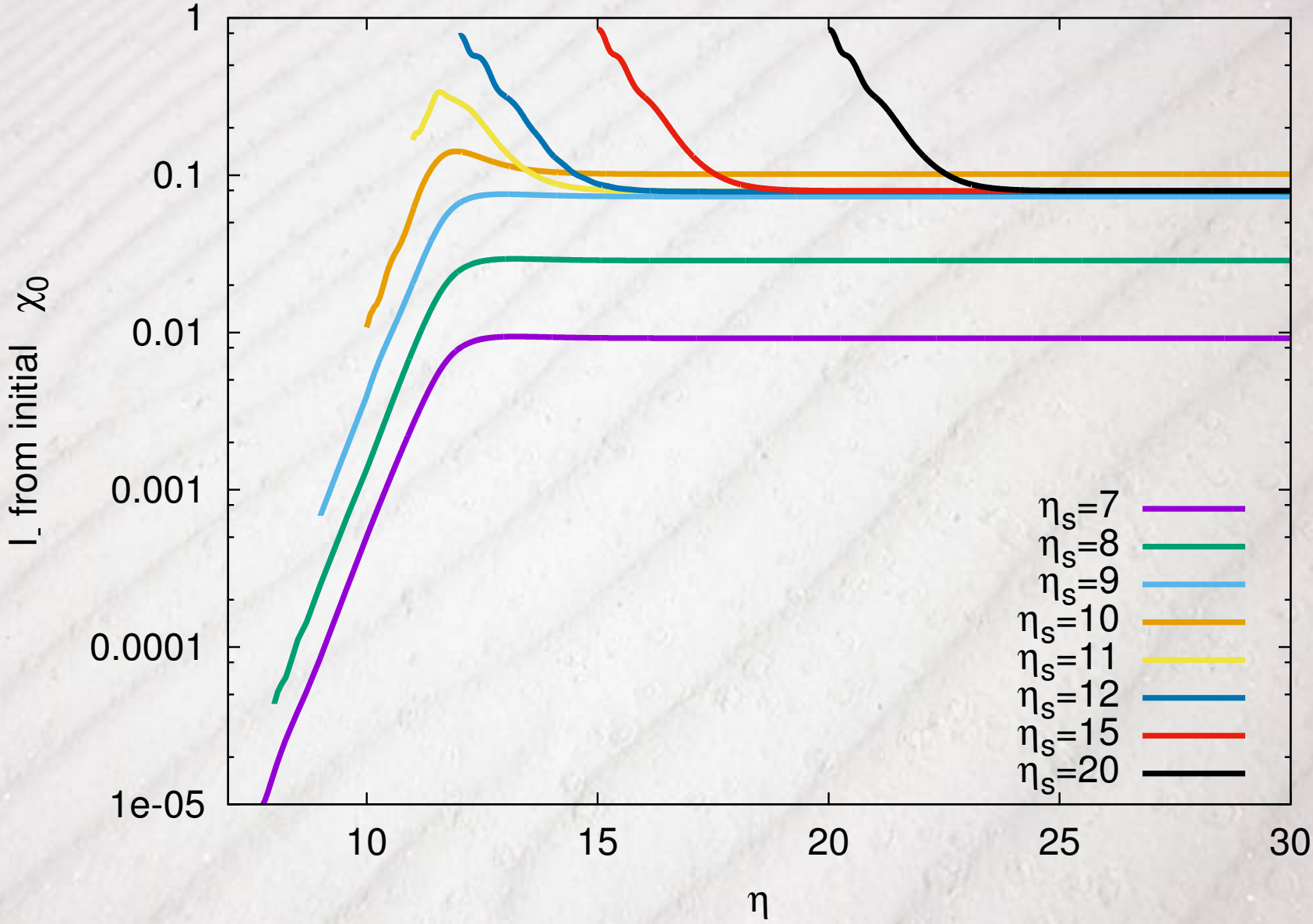






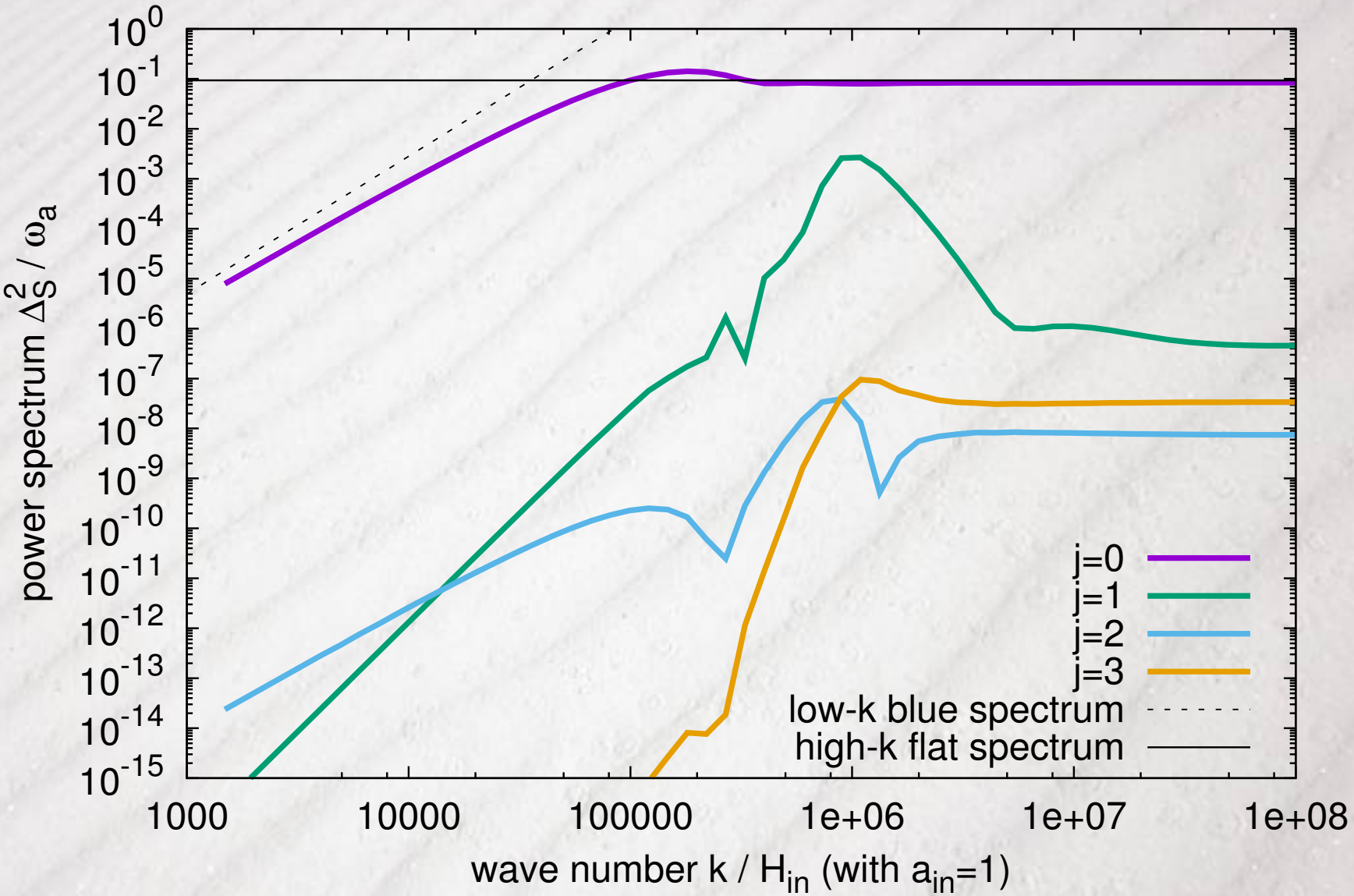
Chung and Upadhye, PRD **95***:023503(2017)[1610.04284]*

Evolution of linear perturbations



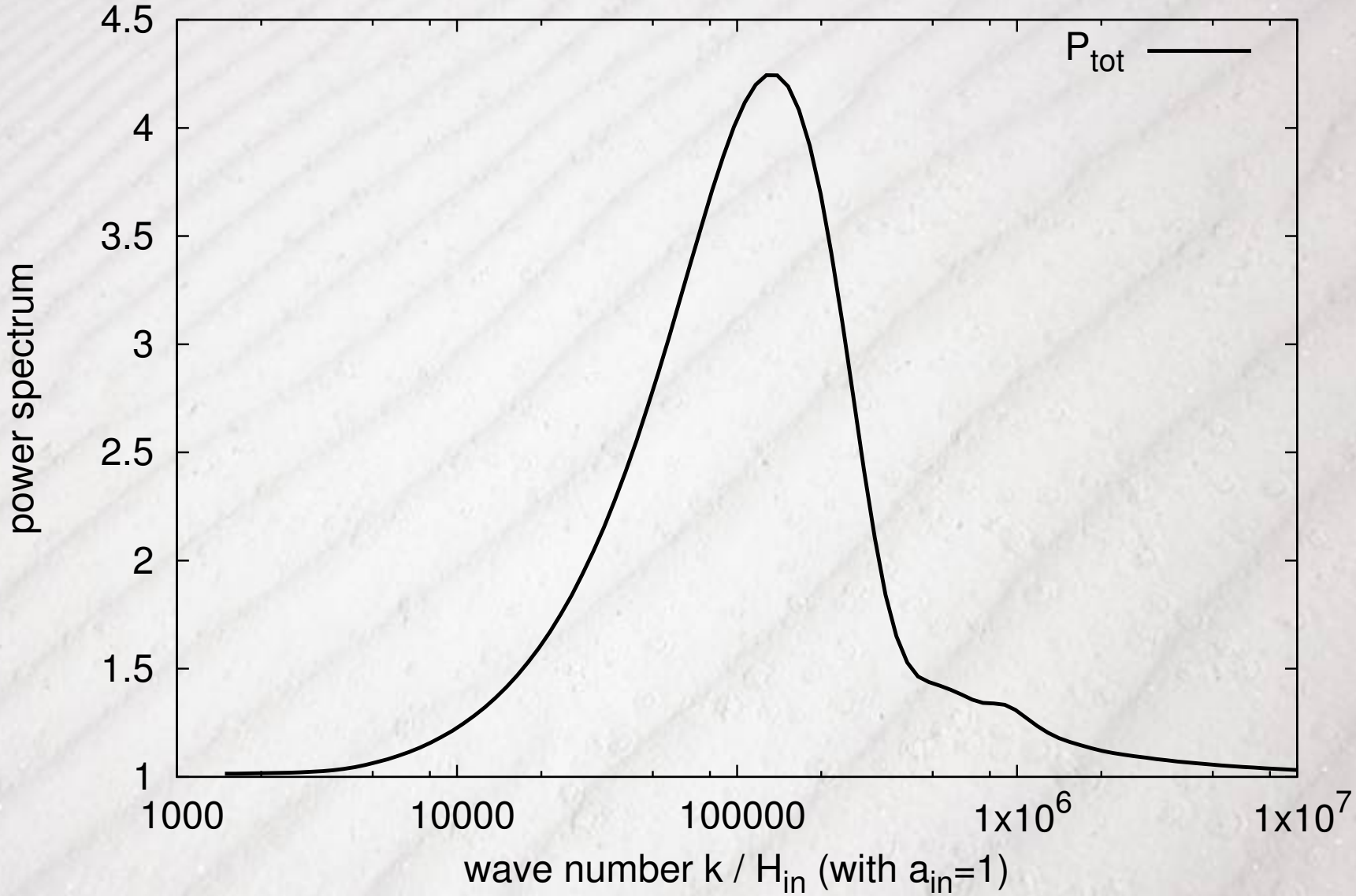
Chung and Upadhye, PRD **95***:023503(2017)[1610.04284]*

Power spectrum, $c_+ = 2.235$



Chung and Upadhye, PRD **95***:023503(2017)[1610.04284]*

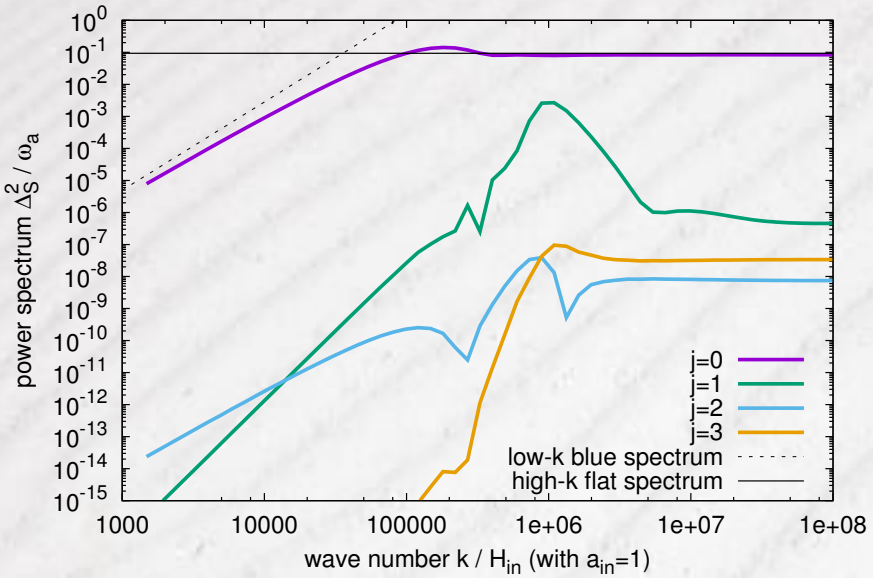
Power spectrum, $c_+ = 2.235$

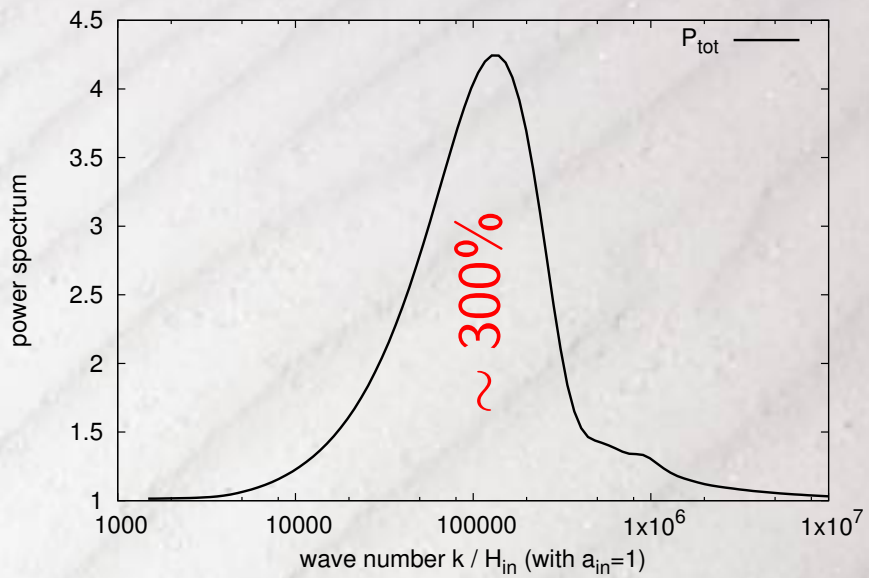


Chung and Upadhye, PRD **95***:023503(2017)[1610.04284]*

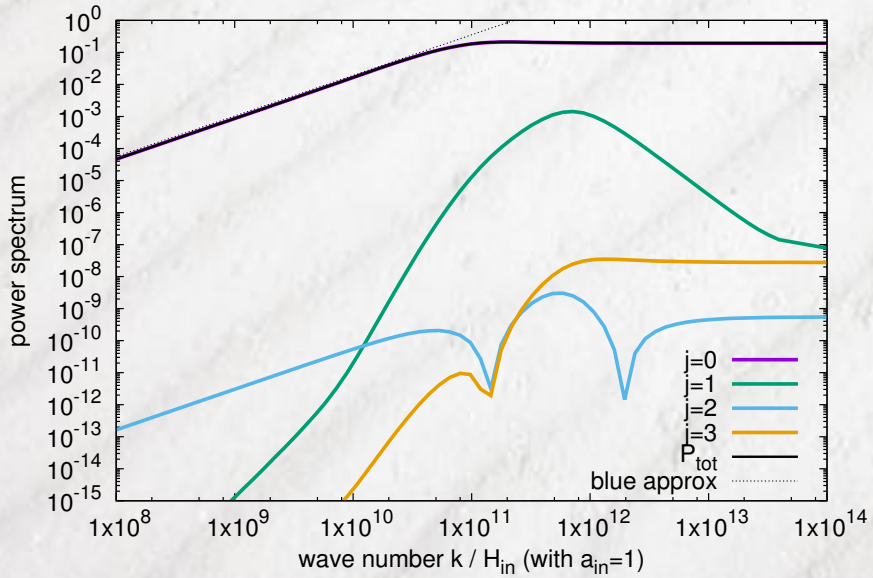
Bluer spectra get bigger bumps

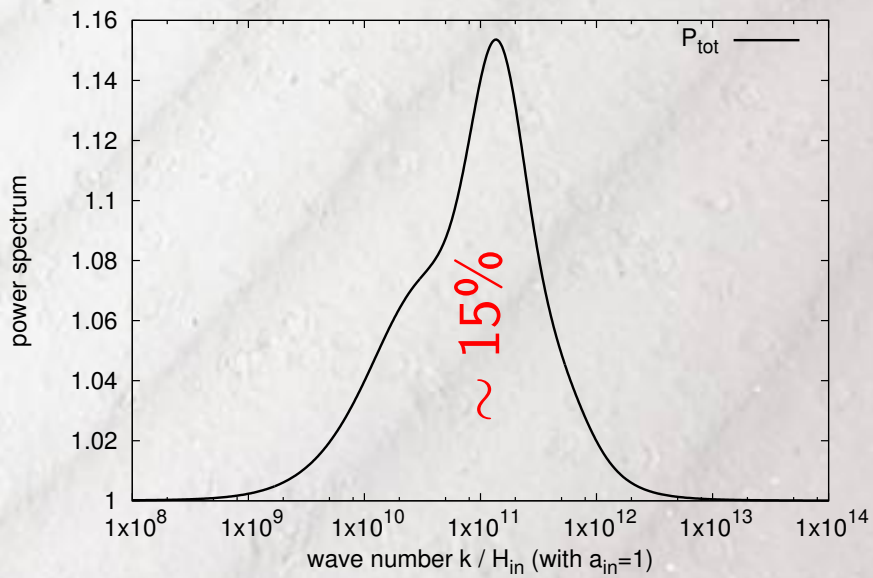
$c_+ = 2.235$





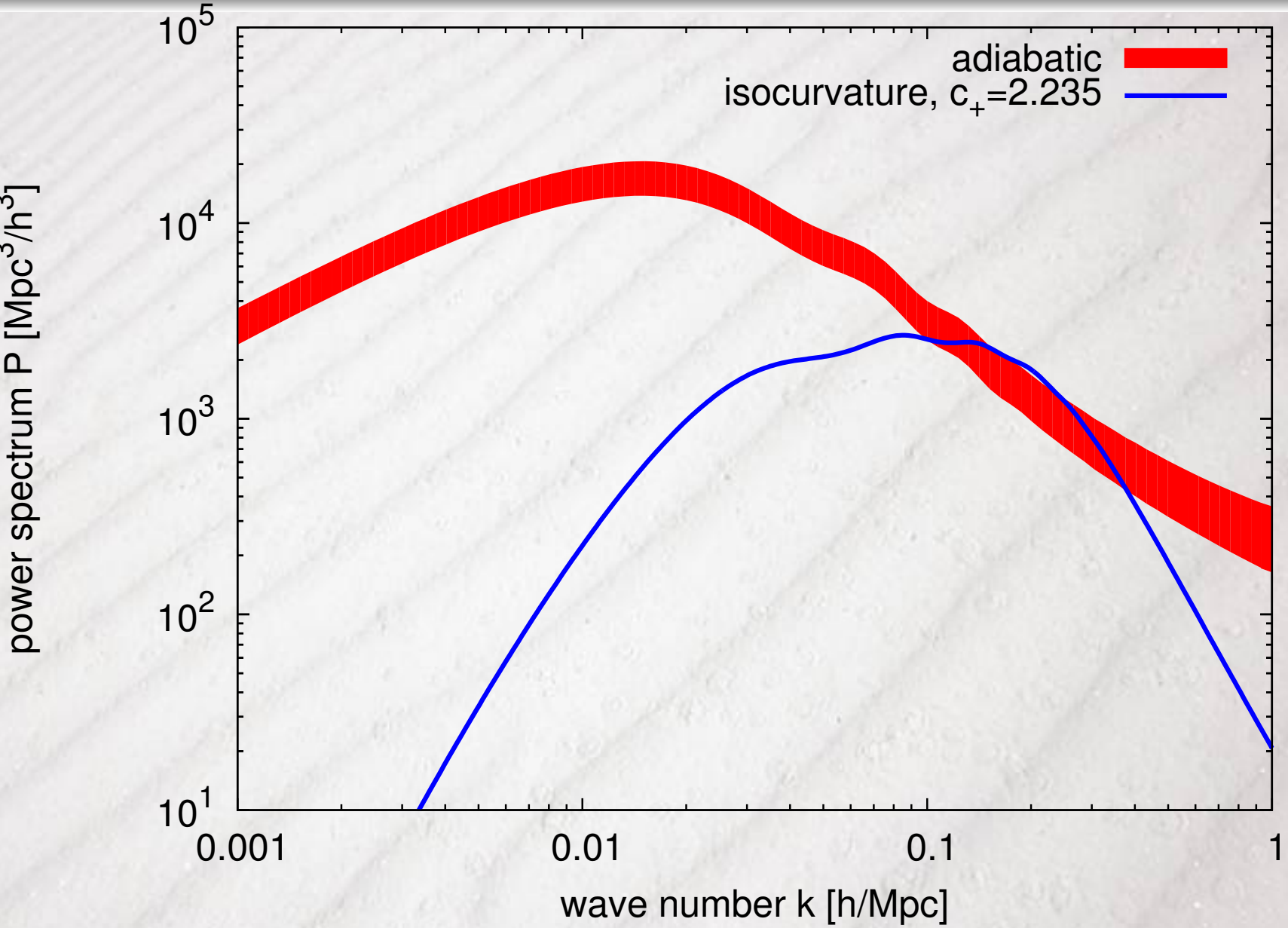
$c_+ = 1.5$





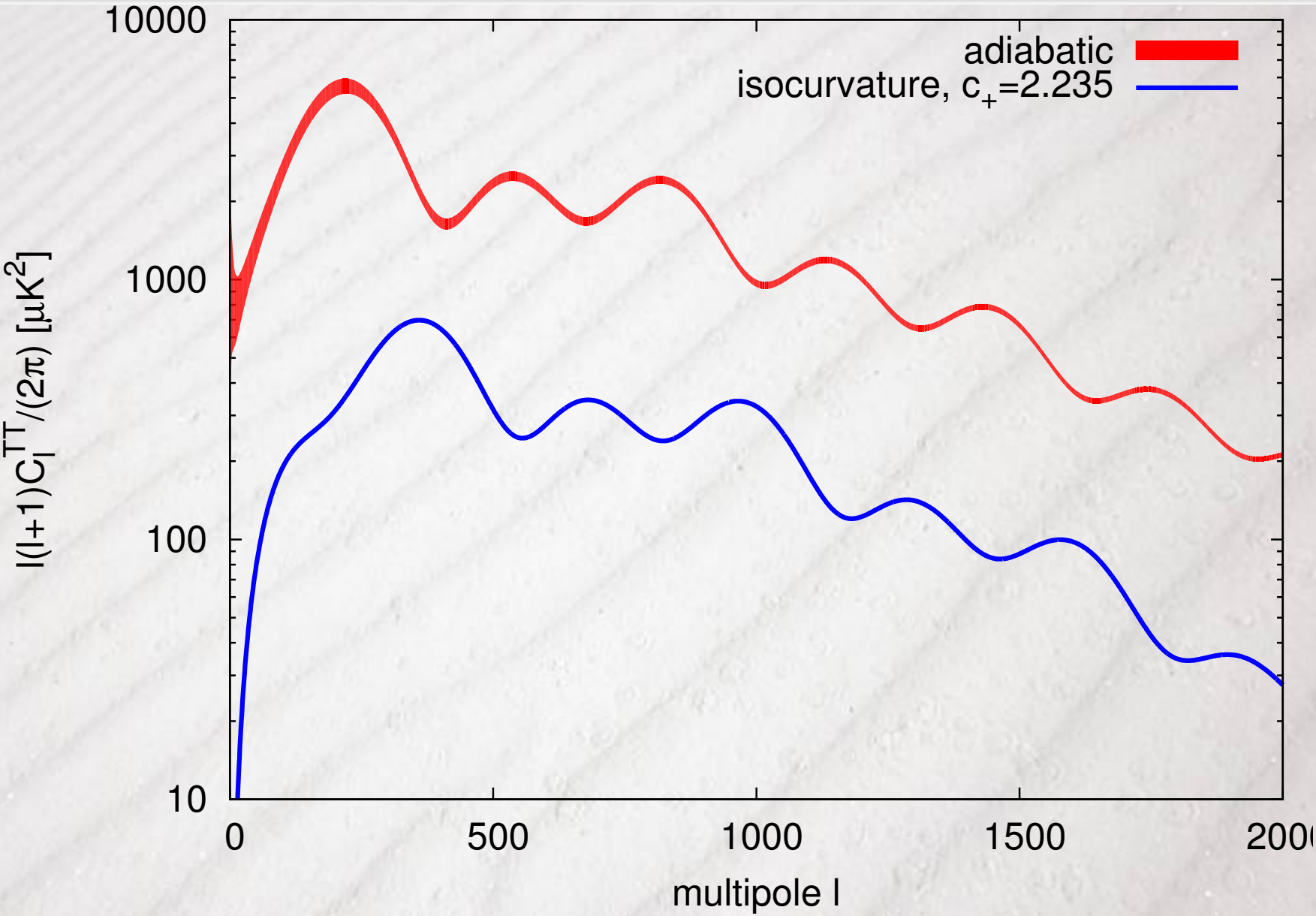
Chung and Upadhye, PRD **95***:023503(2017)[1610.04284]*

Cosmic structure constrains models invisible to the CMB



Upadhye and Chung (2017, in prep.)

Cosmic structure constrains models invisible to the CMB



Upadhye and Chung (2017, in prep.)

Conclusions

1. Cosmic inflation can serve as a backlight illuminating other physics at high energies.
2. Additional fields during inflation will acquire isocurvature perturbations, $P_I(k) = A_I k^{n_I}$. The bluest models must transition to flatter spectra.
3. A simple SUSY axion model can have very blue spectra $2.4 < n_I < 4$ inaccessible to constant-mass models.
4. Power spectra for the bluest models have a characteristic bump at the transition scale that can be used to search for them in current and near-future large-scale structure surveys.
5. For QCD axion candidates, this transition cannot be pushed beyond $k_* = 10 - 20\ h/\text{Mpc}$ for the bluest tilts.